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The Mediterranean Sea

Its history and present challenges

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Marine Bioerosion

26

Christine H.L. Schönberg and Max Wisshak

Abstract

Research conducted in the Mediterranean significantly contributed to our understanding of bioerosion, providing faunistic records and key information about the succession that occurs when fresh substrate is colonized by eroding biota. Bioeroders that have a substantial role in the Mediterranean are microendoliths, sponges, boring mollusks and various grazers. A multitude of environmental factors controls their abundances, diversities and eroding capacities. With ongoing climate change, several of these factors are likely to magnify the effects of bioerosion in the Mediterranean and worldwide. We regard eutrophication as the most important in the Mediterranean, but climate change, especially ocean acidification, will also have an important effect. Should bioerosion levels change, characteristic limestone coasts will be impacted, as will be community and sediment compositions, enigmatic cold-water coral ecosystems, mollusk aquaculture and man-made materials that are submerged. Understudied topics in Mediterranean bioerosion include rates, interactions at community level, as well as direct effects of climate change.

Keywords

Bioeroder densities • Bioeroders • Bioeroding organisms • Bioeroding taxa • Bioerosion rates of microbes • Bioerosion rates • Bioerosion • Chemical bioerosion • Coastal damage • Degradation of hard substrates • Eutrophication and pollution • Global warming • Lithic bioerosion • Macrobioerosion • Mediterranean bioerosion • Microbioerosion • Microendolithic bioerosion • Microendoliths • Ocean acidification • Sponge bioerosion • Wood borers

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Bioerosion in the Mediterranean

The Past of Mediterranean Bioerosion

Endolithic microbes belong to the oldest known life forms on earth with a confirmed age of at least 3.35 Ga (Fliegel et al. 2010). Endolithic cyanobacterian body fossils reach back to the Proterozoic (Golubic and Seong-Joo 1999), other microendoliths appeared in the Cambrian (Glaub and Vogel 2004). 'Deep borers' such as mollusks and worms were first reported from the Silurian (Beuck et al. 2008), and mobile, grazing epiliths from the Triassic (Wilson 2006). According to Bertling (1999, 2002), significant levels of bioerosion in prehistoric Europe co-occurred with the arrival of reefal substrate, and fluctuated with environmental conditions such as sedimentation levels and oxygenation, which favored or suppressed different bioeroders. Sea-level change resulted in changing successions of bioeroder communities and created a high diversity (Santos et al. 2008 and references therein). Bertling (1999, 2002) related increasing evidence of bioerosion to higher turbidity and nutrient levels, which is a recurrent theme in the past of bioerosion (e.g. Highsmith 1980a; Hallock and Schlager 1986; Hallock 1988). Being very responsive to changes in nutrients and having bathymetric distribution ranges, bioeroding sponges and their traces have probably received most attention in the Mediterranean paleontological record (Hartman 1957; Bromley and D'Alessandro 1984, 1990; Wisshak 2008). But due to their narrow ecological niche separation, microendoliths are even better paleoindicators for nutrients, temperature, light, moisture and salinity, particularly from the Late Ordovician onwards (e.g. Perry and Macdonald 2002; Vogel and Brett 2009; Wisshak 2012).

State of Art of Marine Bioerosion Research – What Is Contributed from the Mediterranean?

Since Neumann's (1966) definition of 'bioerosion' as the **degradation of hard substrates by living organisms**, related research has steadily increased (Schönberg and Tapanila 2006, their Fig. 1). While bioerosion research in general is mainly concentrating on tropical coral reefs (8.5 % of the publications are from the Great Barrier Reef alone), the Mediterranean is nevertheless well represented with almost 11 % (Fig. 26.1a). In numbers of publications on bioerosion listed in Thomson Reuter's Web of Knowledge (2011) for the last decade, study locations in southern France and Italy are on place 3 and 4 worldwide (Fig. 26.1b, however, 'France' data include publications on studies conducted in French Polynesia and at Reunion Island). Sites along the Mediterranean coast of Africa were not represented, but European countries contributed about 78 % of studies conducted in the Mediterranean Sea, and Asian countries 22 % (Fig. 26.1b).

As in other areas of research, studies on bioerosion evolved from more descriptive to more applied topics, and the overall knowledge is somewhat patchy and sometimes even contradictive (Schönberg 2008). Presently, faunistic studies on Mediterranean bioeroders are well represented, especially for the Aegean Sea, but functional studies are comparatively rare. Some of the few results available indicate that grazers control settlement success in bioeroders (e.g. Bromley et al. 1990), while other workers claim that by reducing algal cover, grazers are enhancing bioeroder growth (e.g. Cebrian and Uriz 2006). Results on bioerosion rates are scarce from the Mediterranean, with one publication on sponge bioerosion (Calcinai et al. 2011) and a thesis with results on accretion and bioerosion in the Ionian Sea in relation to light and temperature with water depth (Pyko 2009). Long-term studies described the succession of bioeroders in marble blocks over time (e.g. Bromley et al. 1990), with one taxon group preparing the substrate for the next, although it has never been explained what is involved in such a preparation (see Hutchings 2008). In the Mediterranean, but also elsewhere, we do not yet fully understand why endolithic bioeroders evolved to live within hard substrates (e.g. Golubic et al. 1975; Tribollet 2008a). Proposed reasons for this life style include: protection against excessive light or water turbulence, avoidance of predators, competition, parasites and disease, saving maintenance costs, and obtaining nutrients from the substrate (Yonge 1963; Bromley 1970; Ward and Risk 1977; Vénec-Peyré 1996; Glynn 1997; Golubic et al. 2005; Tribollet 2008a; Schönberg and Wisshak 2012). The *Lithophaga* etching agent is known (a calcium-binding mucoprotein, Jaccarini et al. 1968), and microendolithic bioerosion has lately received critical attention (Garcia-Pichel 2006; Garcia-Pichel et al. 2010). However, for most bioeroder taxa using chemical bioerosion we do not know how they proceed, especially at cell level (Vénec-Peyré 1996; Martin and Britayev 1998; Golubic et al. 2005; Hutchings 2008; McLoughlin et al. 2008; Schönberg 2008). And lastly: Because of their endolithic life style, bioeroders are usually ignored in general studies and biodiversity assessments. In combination with their often difficult (ichno) taxonomy and with many species insufficiently or not yet described (e.g. Hutchings 2008; Xavier et al. 2010), we have a long way to go to understand their effects on our seas and oceans.

Agents of Mediterranean Bioerosion

Bioeroders function as a guild (Tapanila 2008) and are linked by numerous interactions, which occasionally make it

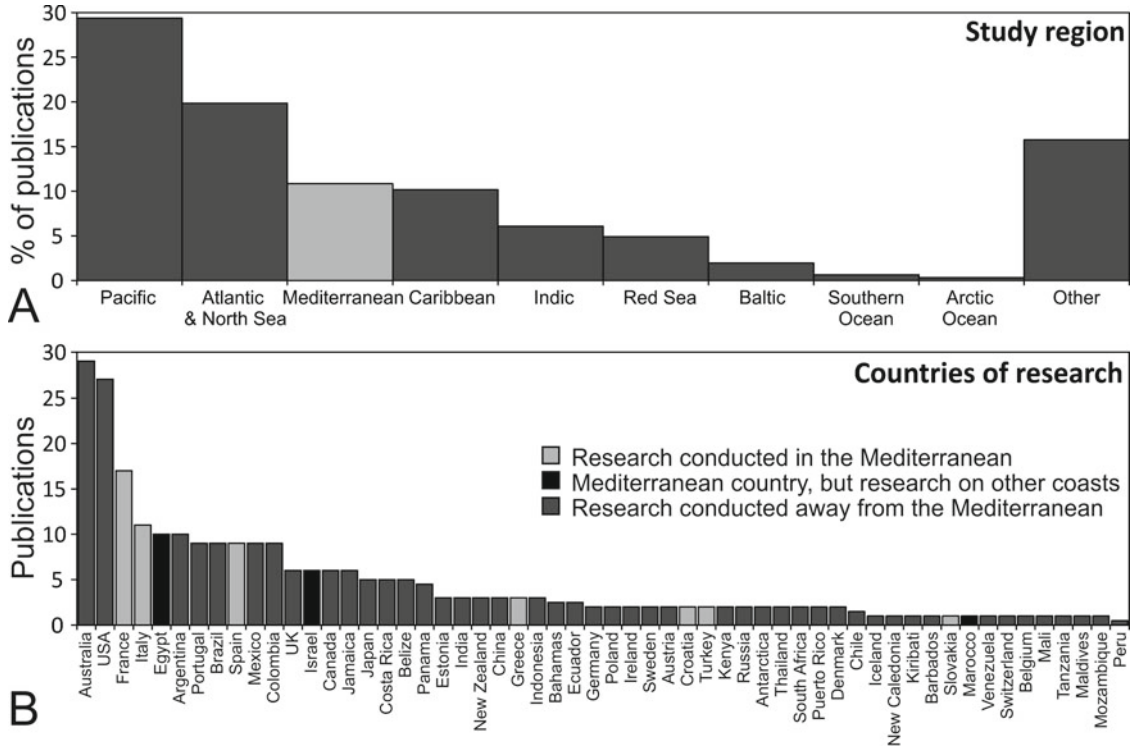

Fig. 26.1 Study locations for bioerosion research over the last 10 years (according to Thomson Reuters Web of Knowledge 2011). (**a**) By ocean or sea. 'Other' is comprised to 1/3 of terrestrial research, to 2/3 of research at unspecified locations. (**b**) By country. Denmark incl. Greenland, USA incl. Hawaii, and France incl. French Polynesia and Reunion Island

difficult to pry apart the roles of separate agents, especially in the warm-temperate biogeographic realm which appears to have a higher biodiversity of bioeroders compared to polar high or tropical low latitudes (e.g. Wisshak et al. 2011). Overall, we regard the following bioeroder groups as the most important in the Mediterranean: microendoliths, sponges, mollusks, and sea urchins. In contrast to tropical settings, fish do not play a significant role in Mediterranean bioerosion (Ballesteros 2006). Wood borers can also be key contributors, but were beyond the scope of the present publication with focus on lithic substrates. Additional details can be obtained e.g. from Yonge (1963), Bromley (1970) and Risk and MacGeachy (1978).

Microendoliths encompass the group of microbial bioeroders such as bacteria, cyanobacteria, microalgae and fungi (e.g. Golubic et al. 1975, 2005; Risk and MacGeachy 1978; Tribollet 2008a). Cyanobacteria and chlorophyte algae are key agents (Fig. 26.2) that were investigated in detail in the Mediterranean near Marseille by Le Campion-Alsumard (1975, 1979), building upon the historic studies carried out by Bornet and Flahault (1888, 1889) and Ercegović (1927, 1929, 1932). Wherever fresh substrate becomes available it is colonized and attacked within days to weeks by pioneering microbes, which then go through a succession of different taxa, reaching an equilibrium after months to years (e.g. Hong 1980; Le Campion-Alsumard et al. 1995; Sartoretto 1998; Naylor and Viles 2002; Beuck et al. 2010). In shallow water, substrate surfaces are grazed by mollusks and echinoids as soon as microendoliths have taken hold, intensifying the effect imparted by the microbes and shaping limestone coasts (e.g. Schneider 1976, 1977; Bromley et al. 1990). Bathymetric patterns and penetration depths within substrates can be related to the compensation depth of photosynthetic microendoliths, with only fungal and bacterial microbioerosion in aphotic depths (e.g. Golubic et al. 1975; Sartoretto 1998; Tribollet 2008b). On the other hand, where light suddenly increases it can cause blooms in the microendolithic communities, possibly producing excess nutrients passed on to neighboring or host organisms (Fine and Loya 2002; Fine et al. 2004). Pace and diversity in development and linked bioerosion rates of microbes are thus highly dependent on bathymetry and the extent of photic zones, as well as the orientation of the substrate (Wisshak et al. 2011).

Sponges are among the best studied bioeroders in the Mediterranean, especially from Spain, France and Italy (e.g. Coll et al. 2010). Excavating sponges establish in newly available substrates after about 2 years and often thrive better on the undersides of substrates or ledges, where competition with coralline algae is lower (Bromley et al. 1990; Cerrano et al. 2001). They etch fine, cup-shaped grooves and mechanically remove lentil-shaped chips that are expelled with the exhalant water to form fine-grained sediment

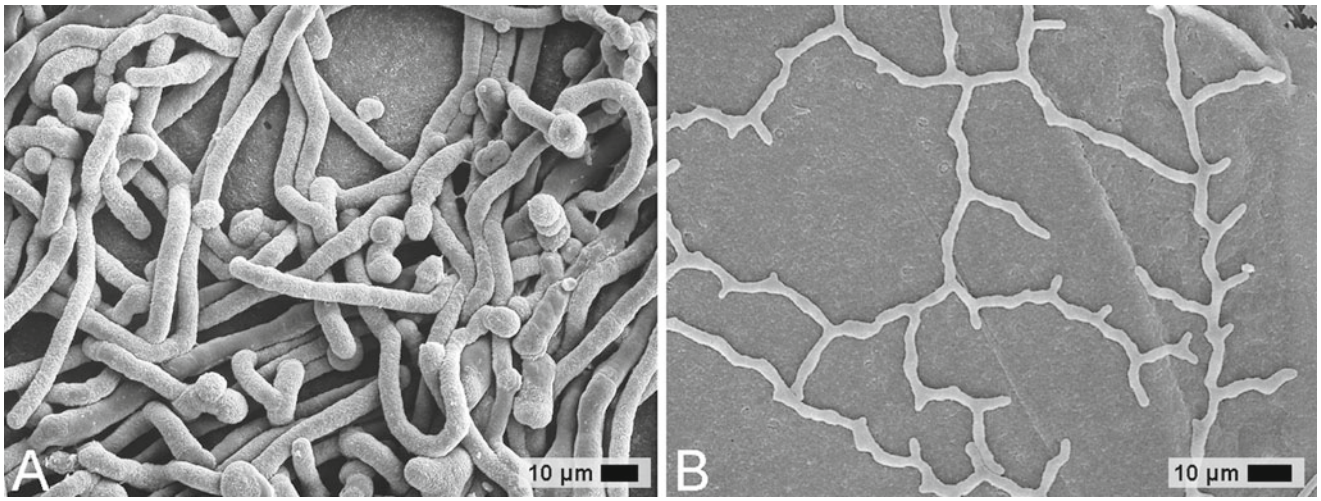

Fig. 26.2 SEM images of epoxy resin casts of microborings produced by the cyanobacterium *Mastigocoleus testarum* (**a**) and the chlorophyte alga *Ostreobium queketti* (**b**) in 15 and 50 m water depth, respectively, recorded on a settlement experiment off the southern Peloponnes, Ionian Sea (Images courtesy of I. Pyko)

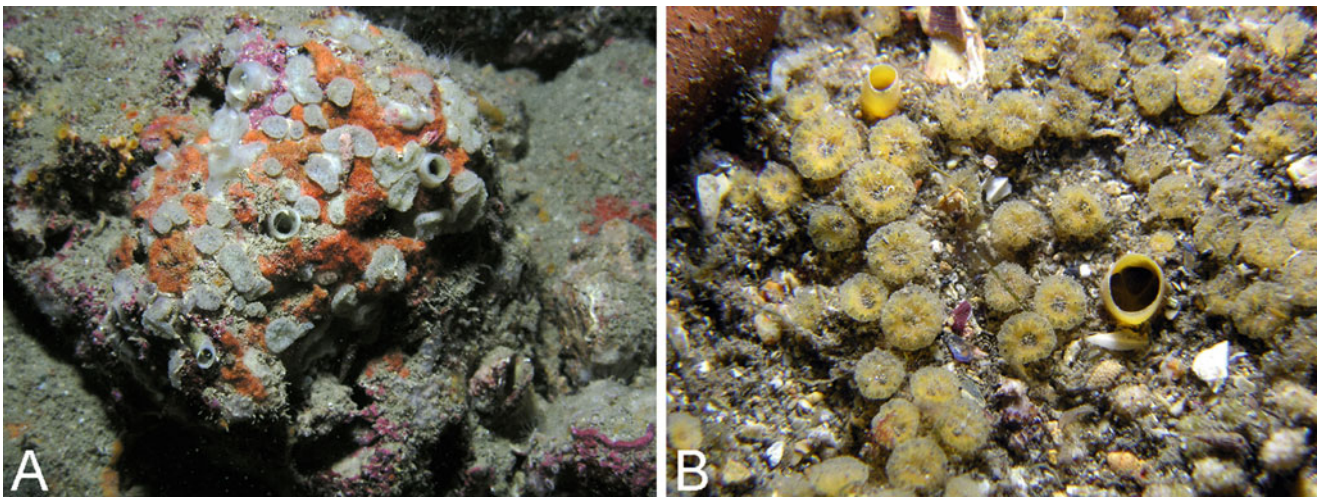

Fig. 26.3 The most common and important bioeroding sponges of the Mediterranean: *Cliona viridis* (**a**, *grayish tissue*) and *Cliona celata* (**b**, *yellow tissue*) (Photographs courtesy of T. Perez)

(Fütterer 1974; Rützler and Rieger 1973). The proportion of chemical etching compared to what is removed as chip has been estimated between 2:98 and 70:30 %, a discrepancy that may well be related to environmental conditions (Rützler and Rieger 1973; Zundelevich et al. 2007; Nava and Carballo 2008). In the Mediterranean *Cliona viridis* is the most abundant and destructive sponge, partly rivaled by species of the *Cliona celata* species complex (Fig. 26.3; e.g. Rosell et al. 1999; Calcinai et al. 2011). Bioeroding sponges have been recognized to be good pollution indicators and biomonitors for environmental conditions (e.g. Hong 1980; Carballo et al. 1994, 1996).

Many mollusks such as chitons and limpets produce 'home scars' or resting scars at places where they most often sit (Fig. 26.4a), and generate grazing traces by removing substrate layer by layer either by radular scraping or by use of acid (e.g. Hutchings 1986). Their intertidal activity is strongly governed by access to water, and areas closer to the water line and spray zone are usually more strongly eroded, which can lead to coastal notch-formation (e.g. Palmer et al. 2003; Neumann 1966). Locally more important than these surface marks are the large hollows mostly produced by bivalves such as pholads, gastrochaenids and mytilids. These mollusks erode by mechanical or chemical means (e.g. Jaccarini et al. 1968; Ansell and Balakrishna Nair 1969; Appukuttan 1969). For reefal areas pholad densities between 50 and 500 individuals per m^2 can occur (Warme 1975; Highsmith 1980b; Loya 1982), but we have no comparable data for the Mediterranean. Here, the slow-growing mytilid lithophags play a considerable role in

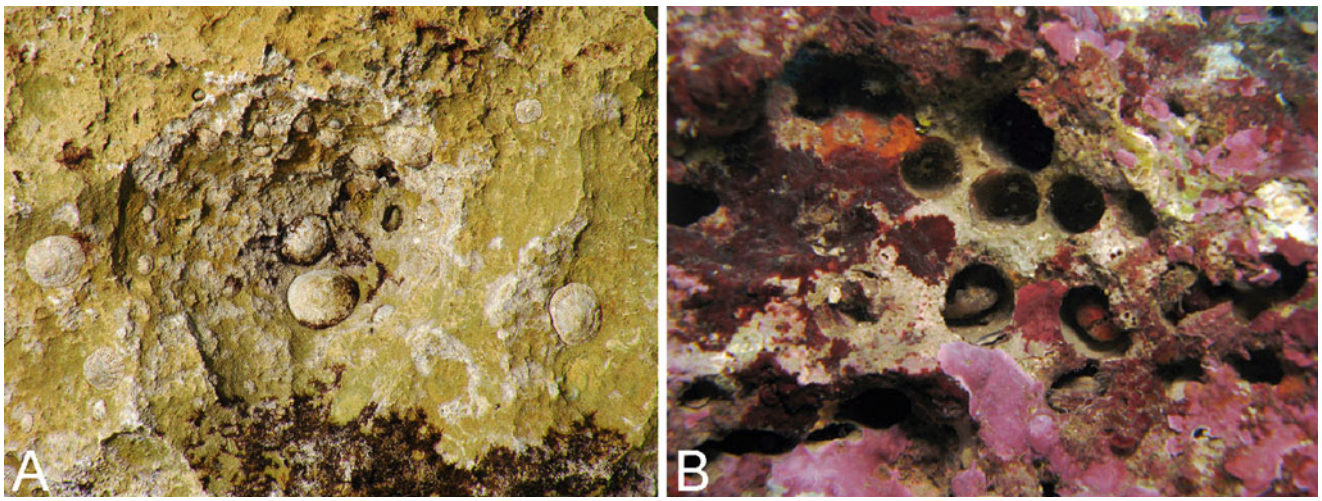

Fig. 26.4 (**a**) *Patella caerulea* and *Chiton olivaceus* with *Patella* resting scars at the Costa Daurada, Spain. (**b**) Borehole battery made by *Lithophaga lithophaga* in the French Mediterranean (**a** – courtesy of J. Martinell, **b** – of A. Antonioli)

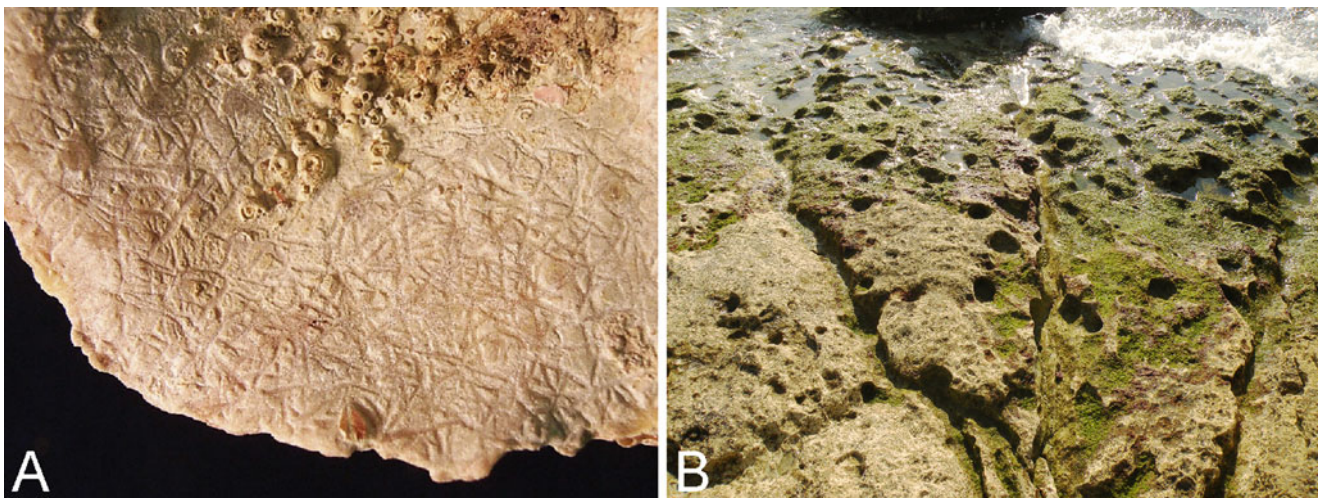

Fig. 26.5 Bioerosion caused by regular sea urchins. (**a**) *Star-shaped* scrape marks made by *Paracentrotus lividus* on an *Anomia ephippium* valve from the Costa Brava, Spain. (**b**) Resting scars produced by *Paracentrotus lividus* at the Costa Daurada, Spain (Photographs courtesy of J. Martinell)

weakening coastal structures (Fig. 26.4b; Kleemann 1973; Devescovi 2009), a process that is magnified by lithophags being harvested as a local delicacy (Fanelli et al. 1994; Russo and Cicogna 1991; Hrs-Brenko et al. 1991; Fraschetti et al. 2001; Guidetti et al. 2003; Devescovi et al. 2005). Therefore, despite being abundant, since 2005 *Lithophaga lithophaga* is a CITES-protected species (Boudouresque et al. 1991; CITES 2011), a restriction which is not necessarily respected by the people (Bianchi and Morri 2000).

Sea urchins appear to play a comparatively small role in Mediterranean bioerosion (Fig. 26.5; Laubier 1966; Sartoretto and Francour 1997), which may in part be related to the fact that they are locally overfished for their roe (Guidetti et al. 2004; Micael et al. 2009). But where urchins have large diameters or their densities reach high levels of at least 20 individuals per 25 m^2 (Sartoretto and Francour 1997) their continuous grazing can maintain 'barren grounds' of mostly coralline algae (Guidetti et al. 2003; Privitera et al. 2005), they can create cup-shaped borings or scrape deep channels into the substrate surface (e.g. Asgaard and Bromley 2008; Fig. 26.5b). Where they graze, sea urchins remove live tissue of other invertebrates or infaunal bioeroders (e.g. Tribollet and Golubic 2005) and can dislodge smaller sessile fauna by bulldozing (Schönberg, pers. obs.). By their rasping activity they produce substrate debris that is defecated as sediments and will accumulate in the area, a process that has been studied in the neighboring Red Sea (Mokady et al. 1996).

Bioeroding worms should be mentioned as well, as they cause the mud blister syndrome in mollusk shells (Fig. 26.6a; e.g. Martin and Britayev 1998). Worms establish themselves in fresh substrate at a rate similar to sponges and appear in a succession of taxa after 2–3 years (e.g. Hutchings 2008).

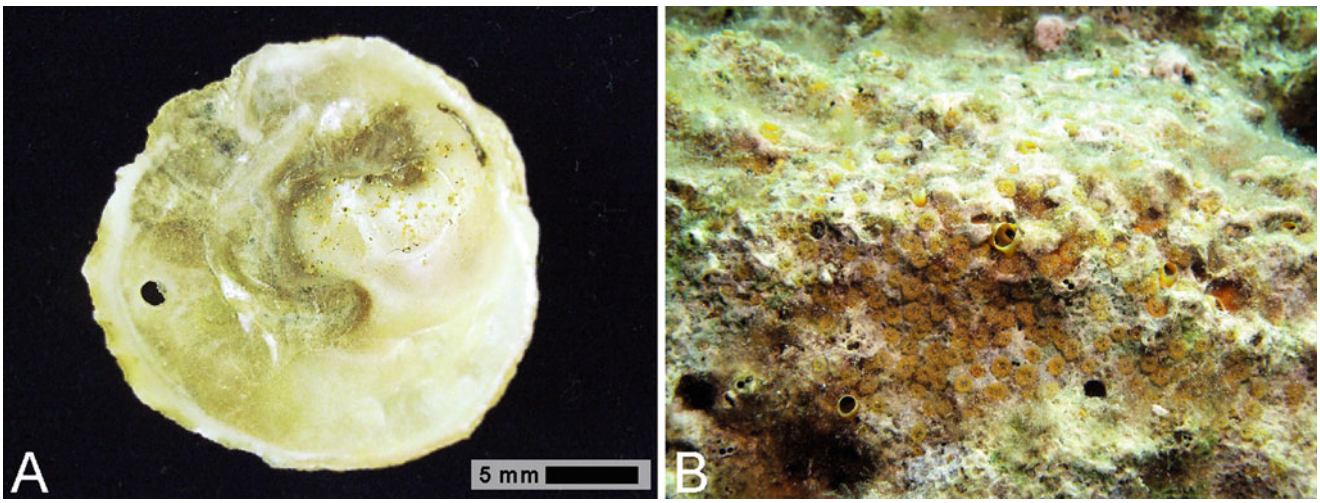

Fig. 26.6 (**a**) Mud blister in an *Anomia ephippium* valve from the Costa Brava, Spain. (**b**) This benthic community of bioeroders in the French Mediterranean is a result of a complicated interplay of e.g. nutrient availability to the filter feeders (*Cliona celata* and endolithic molluscs), competition with coralline algae and other benthic organisms and predation (**a** – courtesy of J. Martinell, **b** – of T. Perez)

Their occurrences vary with environmental conditions, and they can be quite useful as pollution indicators (Hong 1980; Dean 2008). New species can become introduced pests and invasive species (Simboura and Zenetos 2005; Çinar et al. 2011; Zenetos et al. 2011). Polychaetes are a comparatively prominent worm group in the Mediterranean (Feldmann 1937; Hong 1980), while only three species of local endolithic sipunculids are presently identified (Laubier 1966; Sartoretto and Francour 1997). Ironically, Mediterranean worm reefs built by other polychaetes can become subject to bioerosion (Porras et al. 1996; Fornós et al. 1998).

Environmental Factors Acting on Mediterranean Bioerosion and Possible Trends

Many bioeroding organisms such as microendoliths, sponges, worms and endolithic mollusks are sessile and depend on nutrients and/or particulate organic matter being carried to them in the water column. But even mobile grazers can benefit from fertilization if it induces increased algal growth (e.g. Le Bris et al. 1998; Carreiro-Silva et al. 2005, 2009). We therefore assume that in the Mediterranean the strongest local drivers of future trends of bioerosion will be eutrophication and pollution (e.g. Coll et al. 2010). Both factors are thought to aggravate the effects of climate change (Le Grand and Fabricius 2011), which will be of importance in a region that is highly industrialized, densely populated, and has comparatively little exchange with surrounding water masses (e.g. Bianchi and Morri 2000). In particular urban development and river runoff bring about anthropogenic stress known to affect shifts in community structures and to increase bioeroder densities and bioerosion rates (Le Grand and Fabricius 2011 and their table 1). However, the magnitude of nutrient effects are probably the most difficult to determine at community level, because a multitude of cascades and feed-back loops exist that may either enhance the overall effect or confuse the results (e.g.: pollution → increased bacteria concentrations in water column → increased abundances of filter feeding bioeroders → intensive recycling of nutrients → fertilization of microendoliths → increased porosity of substrate → increased efficiency of grazer bioerosion → creation of fresh surfaces aiding settlement of bioeroders; e.g. Corredor et al. 1988; Rose and Risk 1985; Carreiro-Silva et al. 2009; Fig. 26.6b). Further complications arise from the complex interplay of dissolved inorganic nutrients, particulate organic matter, siliciclastic material or pollutants such as heavy metals in the water, with different effects on the various types of bioeroding taxa (fertilization, shading, poisoning, etc.). It is thus hardly a surprise that studies on the influence of the trophic regime on bioerosion yielded partly contradictive results (e.g. Chazottes et al. 2002; Szmant 2002; Carreiro-Silva et al. 2005; Holmes et al. 2009).

To date not many data are available on how climate change may affect bioerosion and whether global warming or ocean acidification may bring about a pertinent change. Within physiological tolerance levels chemical bioerosion itself may be enhanced by increased temperatures due to the simple fact that the reaction rate is accelerated. Overall, global warming is expected to have less severe effects on bioeroding organisms than on calcifiers, because grazers will

move into shade and endoliths are extremely well sheltered and insulated by living within porous, water-retaining substrates that provide shade, and many endoliths can produce cooling currents passing through or over their bodies. Some very common species of bioeroding sponges live in symbiosis with dinoflagellates similar to those in corals, yet they have been observed to be very bleaching resistant during periods of abnormal heating (Vicente 1990; Schönberg and Wilkinson 2001), but the symbiosis may be quite susceptible to light stress (Hill and Wilcox 1998; Schönberg and Suwa 2007; Schönberg et al. 2008). If other bioeroders are as heat resistant as these sponges, the entire guild may indirectly benefit from thermal damage to the calcifiers, which in response to heat stress may be weakened or dead and thus an easy target. In the Mediterranean, warming events are expected to increase, and eastern parts of the basin are more likely to be affected than central and western parts (e.g. Bianchi and Morri 2000; Garrabou et al. 2001, 2009; Coll et al. 2010).

Ocean acidification may have a larger impact on bioerosion than global warming. Most macrobioeroders are either filter feeders or grazers, groups that were found to not be negatively affected or even more common near Mediterranean CO_2 vents (Kroeker et al. 2011). Moreover, many bioeroders at least in part use chemical dissolution to remove substrate, a process which is often thought to be pH dependent or relying on acid production (e.g. Pomponi 1980). Where this is the case, bioerosion is likely to increase in acidified waters (Tribollet et al. 2006). Experimental evidence on how bioerosion might change as a direct reaction to climate change and ocean acidification is scarce. With higher pCO_2 Tribollet et al. (2006, 2009) observed increased penetration depth and bioerosion by microendoliths with a stable community composition. Studies by the present authors investigate the impacts of climate change on macrobioerosion, and results suggest that temperature has little effect on sponge bioerosion (Wisshak et al. unpubl. data), but it will be significantly accelerated by ocean acidification (Wisshak et al. 2012). However, if acidification ever reaches catastrophic levels, reducing the abundance of suitable substrate in the Mediterranean (e.g. Fine and Tchernov 2007; Kroeker et al. 2011), lithic bioerosion will likewise come under pressure. Volcanic activity and hydrothermal seepage in the Mediterranean provides an ideal environment to study consequences of ocean acidification on bioerosion in natural settings (Kroeker et al. 2011; Rodolfo-Metalpa et al. 2011).

Which Assets Will Be Most Likely Affected by Mediterranean Bioerosion?

Mediterranean bioeroder communities are constantly modifying and structuring biogenic as well as abiogenic hardground of coastal areas. This includes the characteristic coralline alga assemblages that are mostly shaped by grazers such as sea urchins (Fig. 26.7; Ballesteros 2006). In extreme cases the urchins can create and maintain 'barrens' devoid of high structural complexity (Privitera et al. 2005). Cover with red algae will in turn reduce settlement success of the larvae of many bioeroders and withstands bioerosion better than other substrates (Hong 1980; Smyth 1989; Chazottes et al. 2002, Ballesteros 2006), although bioeroding sponges frequently penetrate it (Cotte 1914; Cerrano et al. 2001).

Many bioeroders rework and produce considerable amounts of sediment. For example, sponge-generated sediments in the North Adriatic Sea make up about 2–3 % (Fütterer 1974). Higher bioeroder densities or shifts in their community compositions would mean that both their influence on the hard-bottom morphology and the sediment quality in their habitat will change (Hutchings 1986).

Diverse bioeroder communities inhabit slow-growing solitary, (pseudo)colonial and cold-water Mediterranean corals (Fig. 26.8a; Bromley 2005; Wisshak 2008; Mastrototaro et al. 2010), which they can infest to a high degree (20–75 %, Bavestrello et al. 1997; Corriero et al. 1997; Cerrano et al. 2001), deform them (Beuck et al. 2007), cause a higher risk of fragmentation by removing up to 70 % of the skeleton (Beuck et al. 2010), overwhelm early life stages (Calcinai et al. 2000) or cause wide-spread mortality (Corriero et al. 1997). Bioeroding sponges in particular are a devastating pest in Mediterranean corals and among others attack the precious red coral *Corallium rubrum* (Fig. 26.8b; e.g. Melone 1965; Maldonado 1992; Bavestrello et al. 1996; Calcinai et al. 2000, 2002, 2008), the overexploited Mediterranean 'red gold'. *Corallium* has been used as a gemstone since ancient times (Pronzato 2000), historically supported trade between Mediterranean countries and India, and is part of the Greek mythology (Medusa's head, Poseidon's Palace; De Simone 2010 and other contributions in the same volume). Bioeroding sponges are very common in Mediterranean *Corallium* colonies (Barletta and Vighi 1968). Corriero et al. (1997) stated that coral survival is strongly correlated with severity of infestation with these borers that are able to kill colonies that reach 4 years of age, while they only become reproductive at 2 years or later (Santangelo et al. 2003). Should the infestation rate by sponges increase, the traditional Mediterranean culture and trade based on the already threatened red precious coral may well become a thing of the past (Weinberg 1991; Garrabou et al. 2001, 2009; Costantini et al. 2007). As many cold-water reefs support a very diverse associated fauna, a reduced abundance of such corals would affect other taxa as well (e.g. Mastrototaro et al. 2010).

Bioeroders furthermore invade mollusk shells and can cause considerable damage on local oysters and mussels. Aquaculture hatcheries generate considerable profit for at least six Mediterranean countries (Fisheries and Aquaculture

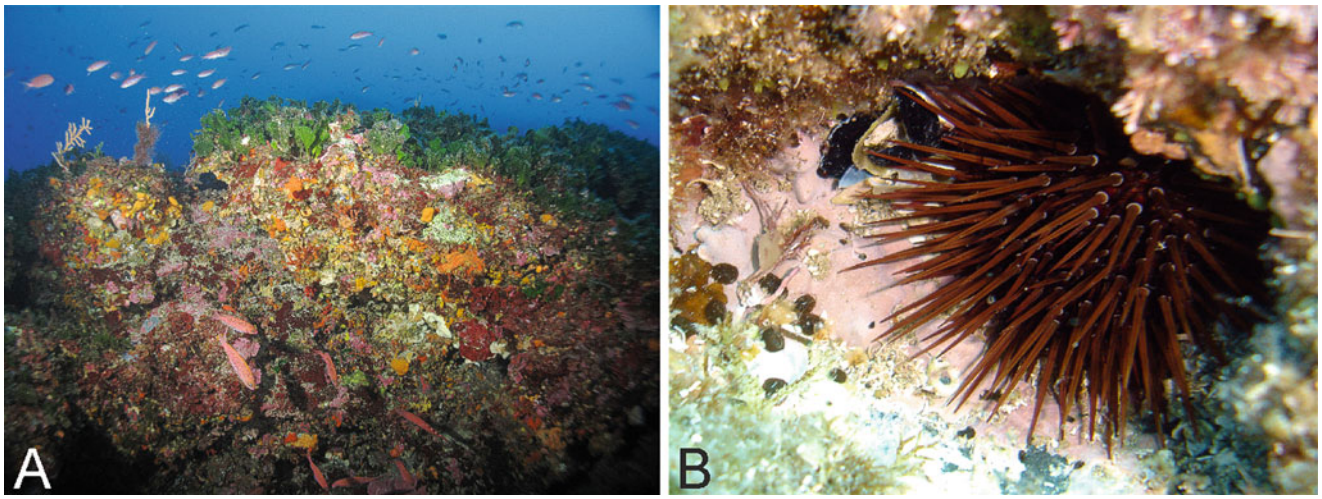

Fig. 26.7 The 'coralligène' (**a**) and some of the main players involved in shaping this habitat (**b**): the sea urchin *Paracentrotus lividus*, the sponge *Cliona viridis* (*brown papillae* in the *lower left*) and coralline algae (in the background) (**a** – courtesy of T. Perez)

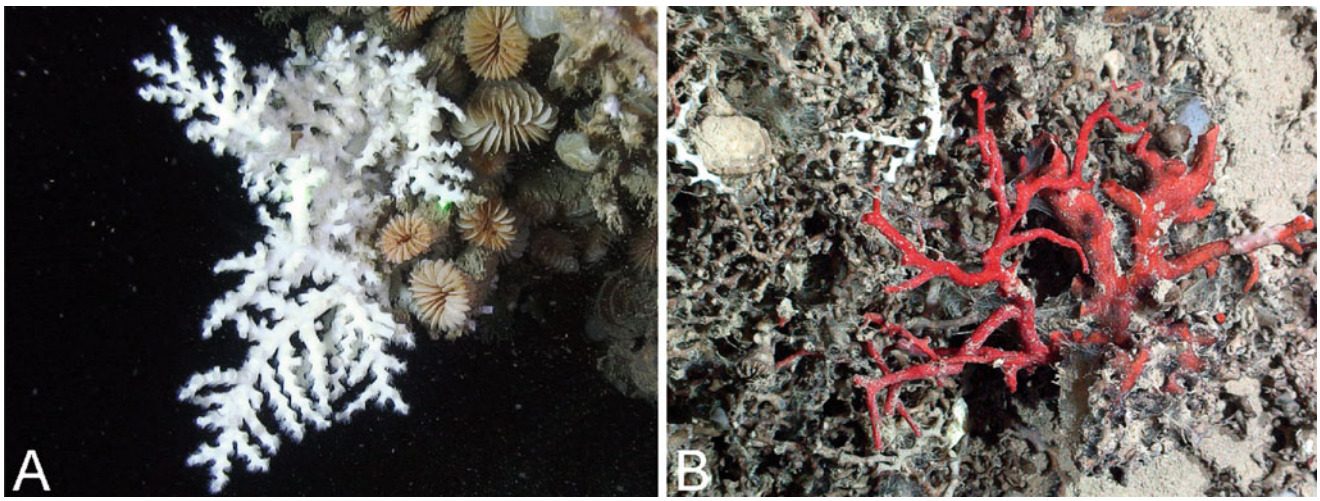

Fig. 26.8 (**a**) The cold-water corals *Madropora oculata* and the solitary *Desmophyllum dianthus* from about 400 m water depth in the Lacaze-Duthiers Canyon near Banyuls-sur-Mer, France. (**b**) Colony of the red coral *Corallium rubrum* from the Linosa Trough in the Pelagian Island group showing clear evidence of bioerosion and subsequent deformation (**a –** courtesy of Senckenberg/MARUM, **b** – courtesy of L. Beuck and A. Freiwald)

Department 2011). France is a large, traditional oyster producer, ranking among the top producer and consumer countries of the world, with an annual production of 9500 t in the Thau Lagoon (Héral 1989; Buestel et al. 2009). Losses related to bioerosion have been historically observed (Carazzi 1895) and may significantly increase in the future. While oysters are readily attacked by various bioeroders (Labura and Hrs-Brenko 1990: up to 89 % oysters by *Polydora hoplura*, Rosell et al. 1999: 100 % of oysters by two species of sponges), mussels are to a much lesser extent and degree, but often with more devastating effects to their shell stability and thus to survival from predation (Lauckner 1983).

Bioerosion in combination with changing weather patterns and increased frequencies of severe storms may also result in more coastal damage, because bioerosion reduces the security of attachments and breaking strength of the invaded organisms and materials (Tunnicliffe 1979; Highsmith 1980b; Mitchell-Tapping 1983; Clark and Morton 1999; Scott and Risk 1988). Microendoliths and urchins can attack volcanic materials such as dolerites, balsanites and volcanic glass (Allouc et al. 1996; McLoughlin et al. 2008), which would play a role in those parts of the Mediterranean that have a geological history of volcanism (e.g. Aiello et al. 2001). And as final reminder of cause-and-response to our actions: Man-made environmental changes influencing bioerosion will also damage man-made or man-shaped substrates. A number of bioeroding organisms such as sponges and pholad bivalves are able to riddle and whittle away artificial materials or

Fig. 26.9 Greek statues from the Athens National Museum of Archaeology retrieved from a shipwreck in the Aegean. They were exposed to marine bioerosion for about 2100 years, the degree of damage depending on the sediment cover. (**a**) The statue's eyes were replaced by a brachiopod and a pholad boring. (**b**) Parts of the statue that were not covered by sand were strongly affected by bioerosion (Photographs courtesy of R. G. Bromley and U. Asgaard)

structures (Scott 1991; Brusco et al. 2005). Other mollusks are destabilizing breakwater boulders in the Adriatic (Devescovi and Iveša 2008) and can easily penetrate concrete containing calcium, as can some sponges and polychaetes (Yonge 1963; Scott et al. 1988). Echinoids have been suspected to attack even steel pilings (Emery 1960) and are known to pry grains out of granite at a faster rate than they would erode limestone (Bromley 1970). And in conclusion, bioerosion also affects submerged works of art, e.g. Greek marble statues or submerged mosaics in the Aegean (Fig. 26.9; Bromley and Asgaard 2004; Ricci et al. 2008).

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